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Real Scale Halon Replacement Testing Aboard the Ex-USS Shadwell: Phase II - Post Fire Suppression Compartment Characterization

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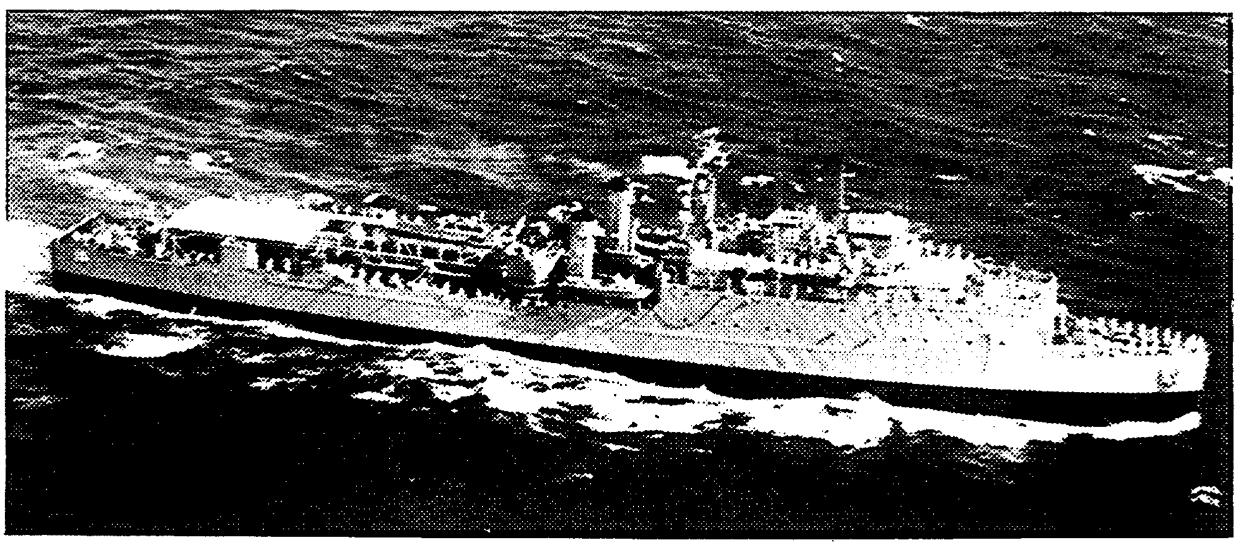

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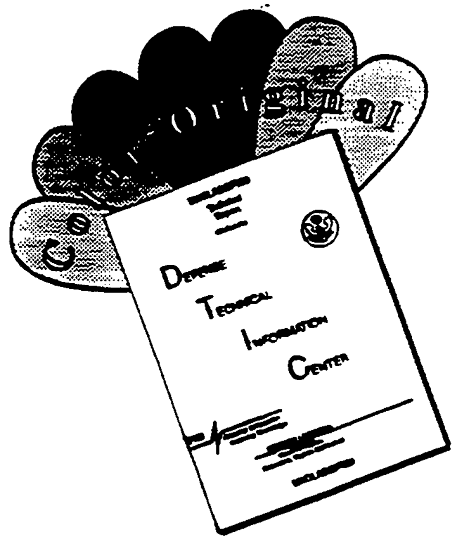

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13. ABSTRACT (*Maximum 200 words*)

This report describes real scale Halon 1301 replacement tests conducted aboard the ex-USS SHADWELL. These tests were conducted in a simulated shipboard machinery space. The floodable volume of the space was 370 m^3 (13,000 ft^3). Most tests were conducted with heptafluoropropane (HFP, HFC-227ea, C_3F_7H) with limited baseline comparison tests conducted with Halon 1301. Parameters such as fire extinguishment, oxygen depletion, agent concentration inhomogeneities, thermal statification and hydrogen fluoride production were examined.

Compartment reentry after a fire incident on a U.S. Navy ship may be the most critical part of the firefighting event and potentially the most dangerous. Unwanted reignitions and back-draft explosion can occur. Toxic and hazardous by-products that result from halocarbon fire suppression are likely to be present. Depleted oxygen and combustion gases, such as carbon dioxide and carbon monoxide, will also exist. This report describes recent tests in which post-fire suppression compartment characteristics and their impact on compartment reclamation were investigated.

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CONTENTS

REAL SCALE HALON REPLACEMENT TESTING ABOARD THE *ex*-USS SHADWELL: PHASE II - POST FIRE SUPPRESSION COMPARTMENT CHARACTERIZATION

1.0 INTRODUCTION

During initial real scale Halon 1301 replacement testing (Phase I) aboard the *ex*-USS SHADWELL, (reference (a)), tests were conducted to identify the clean replacement agent of choice for U.S. Navy shipboard machinery spaces, (references (b) - (d)). The primary threat in these spaces is pressurized flammable fluids. The characteristics of the candidate replacement agents such as fire suppression, reignition prevention effectiveness, agent pipe flow discharge properties, agent distribution, reaction/decomposition products, materials corrosivity, and materials compatibility were examined. Phase I testing also examined the effects on fire suppression and hydrogen fluoride (HF) production by variations in agent discharge rate or agent discharge nozzle geometry, design concentration, fire size, and fuel type. The clean agent recommended for consideration to the Naval Sea Systems Command (NAVSEASYSCOM) for use in machinery spaces on new construction U.S. Navy ships is heptafluoropropane, HFP, (HFC-227ea, C_3F_7H, manufactured by Great Lakes Chemical Corporation as FM-200), (reference (e)).

The test compartment's floodable volume was reduced from 755m^3 (26,600ft^3) to 370m^3 (13,000ft^3) during Phase II testing by isolating and testing in one half the Phase I compartment. Parameters such as fire extinguishment, oxygen depletion, agent concentration inhomogeneities, thermal stratification, and HF production were examined as they were in Phase I testing, the results of which have been previously reported, (references (f), (g)). During this test phase, however, a more detailed study of the post fire suppression compartment characteristics was performed.

Phase II tests were conducted according to the Test Plan, (references (h), (i)). Phase II testing had four main objectives. First, to aid in the determination of the optimum post-fire suppression firefighting team reentry and hold times in terms of temperature, hydrogen fluoride (HF) concentration, depleted oxygen and combustion gas concentrations. The hold time is the period between agent discharge and subsequent ventilation. Second, to evaluate the use of an NRL innovation, the Water Spray Cooling System (WSCS), to enhance fire extinguishment, reduce reignition potential, reduce HF production, mitigate generated gas phase HF, and quickly reduce compartment temperatures. Third, to determine if modified Navy agent delivery hardware (tank valves, check valves, and flexible hoses) can provide a more rapid agent discharge. Fourth, to determine the effects of doubling the number of agent discharge nozzles on agent distribution. This paper addresses the first objective. The other objectives have been addressed previously, (references (j), (k)).

Little quantitative information currently exists regarding post-fire suppression compartment reentry (by the firefighting team), desmoking, and venting for Halon 1301 systems. The reduced safety margins of the replacement agents and increased HF threat necessitate such

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testing. Chapter 555, Section 6, of the U.S. Naval Ships' Technical Manual (NSTM) is limited to Halon 1301 regarding halogenated total flooding fire suppression agents in machinery space applications, (reference (l)). The current testing may help provide guidance for future NSTM revisions regarding reentry and venting after HFP fire suppression.

Compartment reentry is a very critical part of the firefighting event, and potentially the most dangerous. Fleet doctrine states reentry should not be attempted for at least 15 minutes after Halon 1301 machinery space total flooding fire suppression, (reference (l)). Desmoking with the installed ventilation system proceeds when the risk of reignition has been minimized by the reentry team. Phase II testing explores the sequence with which reentry and ventilation proceeds, and means of decreasing reflash potential.

During Phase II testing, a 15 hold time was most often used, although some tests were conducted with 5 minute or 30 minute hold times. Reignition attempts were performed at one minute intervals until a successful reignition occurred during venting. Safety team reentry in these tests occurred only after compartment ventilation had been restarted.

2.0 TEST COMPARTMENT

The test compartment was located between Frames 22 and 29 on the upper and lower levels of the 4th deck. The approximate dimensions were 8.5m (28ft) forward and aft, and 6.1m (20ft) high from the keel to the overhead of the upper level. The compartment's width was 8.5m (28ft) at Frame 29 narrowing to 7.0m (23ft) at Frame 22. The test compartment's floodable volume was reduced from 755m^3 (26,600ft^3) to 370m^3 (13,000ft^3) during Phase II testing by isolating and testing in one half the Phase I compartment. One discharge system was for HFP with four discharge nozzles, two on each of the upper and lower levels. A second discharge system was installed for benchmark tests using Halon 1301 with two nozzles on each of the upper and lower levels. The third discharge system tested modified discharge hardware using the 4-nozzle HFP piping. The fourth discharge system was used to investigate the effect of doubling the number of agent discharge nozzles. This discharge system was used with HFP only and was divided into four nozzles in both the upper and lower levels. An isometric diagram of the compartment is shown in Figure 1. Since the compartment dimensions changed between Phases I and II, there was concern that agent distribution characteristics also changed. Figure 2 shows the agent concentration measured at the primary fire threat location, Fire 1. The measurements were made using a grab sampling technique with subsequent gas chromatographic analyses. The concentrations are normalized to correct for differences in the design concentration used in each test. The sampling times were not the same in each test, so there are points not common to both concentration profiles. The concentration profiles for the two tests are similar.

3.0 INSTRUMENTATION

The test compartment and associated systems were highly instrumented with both physical and chemical measuring devices. The agent discharge system was instrumented to measure pressure, temperature, and mass loss. Pressure transducers were located at one cylinder valve, one check valve, the agent discharge manifold, and at each of the discharge nozzles. Thermocouples were installed in the same locations. Mass loss during agent discharge was measured by a load cell transducer. The WSCS system was equipped with an ultrasonic flow meter and a single thermocouple. Temperature measurements were made throughout the space and at each fire and telltale. Two transducers were used to measure compartment pressure in each test. A decibel meter and a microphone were used to measure and record noise levels during agent discharge. Complementary techniques were used to measure gas phase concentrations of the various species of interest. The permanent gases CO, CO_2, and O_2 were measured by both continuous flow analyzers, and intermittent grab sampling with subsequent gas chromatographic analyses. Agent concentration was measured by continuous flow analyzers, grab sample/gas chromatography (GC), and by a Fourier Transform Infrared Spectrometer (FTIR). Both HF and HBr (generated only during Halon 1301 tests) were measured by continuous flow electrochemical cell halogen acid gas analyzers, (reference (m)), grab sample/ion chromatography (IC), and FTIR. Each test was videotaped using both visible and infrared wavelength cameras.

A UNIX-based Massachusetts Computer Corporation (MASSCOMP) computer, Model 5600, acquired data from fire, telltale, compartment, and WSCS TCs, continuous analyzers, and WSCS flow transducers. An MS/DOS-based Experiment Running PC (ERPC), with LabVIEW Full Development data acquisition software, was used for both data acquisition and instrumentation / activation control. The ERPC acquired data from air flow measurement devices, compartment and agent discharge system pressure transducers, agent discharge systemTCs, the decibel meter, and the agent discharge bottle load cell. The ERPC also activated the agent discharge system, and both agent and acid grab sample solenoids.

4.0 COMPARTMENT FIRES

The fire specifications are listed in Table 1. Three simultaneous test fires and 17 telltale fires were ignited in the compartment. Naval Distillate F-76 was used as the test fire fuel. The telltales (TT) were fueled with n-heptane. Fire 1, which was the largest fire threat, was a combination pan and spray fire. Photograph 1 shows Fire 1 approximately 20 seconds after ignition. The photograph shows a long side of the fire pan viewed from forward looking aft. The height of the flame sheet that is visible in Photograph 1 is approximately 2.0m (6.6ft). The flame sheet extends into the upper level of the compartment and is obscured from view. The inverted L-shaped structure to the right of the vertical stiffener in Photograph 1 is the HFP agent discharge nozzle. Evidence of burning fuel cascading over the side of the fire pan can be seen in the lower left corner of Photograph 1.

Fires 2 and 4 were low flow rate spray fires that for some tests also contained some Class A combustible material. Fire 2 is shown in Photograph 2. The three small fires (vertical tree) to the left of Fire 2 are telltales. Fire 3, which was used during Phase I testing, (reference (b)), was not used due to compartment modifications that limited access and personnel safety at its location.

Table 1: Fire Specifications

Fire	Pan Size (m x m)	Pan Area (m^2)	Pan Fire Size (MW)	F-76 Diesel Spray Flow Rate (L/m)	F-76 Diesel Spray Fire Size (MW)
1	2.4 x 0.9	2.2	4.5 [a]	5.7 - 7.9	3.3 - 4.7 [a]
2	-	-	-	0.7 - 0.8	0.09 - 0.1
4	-	-	-	0.7 - 0.8	0.09 - 0.1
TT	6.4cm diam	0.003	0.003	N.A. [b]	N.A. [b]

a. The pan fire burning interval overlaps the spray fire burning interval.
b. Not applicable.

5.0 FIRE SUPPRESSION AGENTS

Tests with HFP were conducted at a 10.1% design concentration. The design concentration was based on the compartment's floodable volume, 370m^3 (13,000ft^3), calculated at 21°C (70°F). Benchmark Halon 1301 tests were conducted at a 5.2% design concentration based on the floodable volume calculated at 10°C (50°F). The temperatures are a result of a difference in the concentration/temperature usage envelopes for these agents. Halon 1301 has a design concentration envelope between 10°C (50°F) and 66°C (150°F) for existing shipboard systems. HFP has a design concentration envelope between 21°C (70°F) and 54°C (130°F) for future U.S. Navy surface ships, (reference(e)). The reported design concentrations were based on the lower limit of the design concentration envelope.

6.0 TEST SEQUENCE

Phase II testing was divided into seven Series. Table 2 lists particulars of each test Series. Series 1 tests were conducted to refine test running procedures, and observe oxygen depletion, fuel burning times/rates, and temperatures as a function of ventilation without agent discharge. The effect of WSCS on the test fires without an agent discharge was also determined. Series 2 tested the agent discharge system configuration and provided distribution characteristics without test fires. Series 2 also provided additional data for validation of the Transient Flow Analysis/Transient Flow Halon (TFA/TFHAL) pipe flow models, (reference (n)). One test was done with the 8-nozzle discharge system. In Series 3, the effects of different hold times on acid decay, oxygen and agent concentration, compartment temperatures, and reignitions were determined. These tests were conducted without the use of WSCS. The effect of HFP/WSCS on acid decay, oxygen and agent concentration, compartment temperatures, and reignitions was determined in Series 4. Series 5 tests were conducted to measure the effect of WSCS activation prior to HFP discharge on fire extinguishment, peak HF production, and compartment temperatures. Series 6 tests were benchmark Halon 1301 tests one of which employed WSCS. Modified U.S. Navy discharge system hardware was tested in Series 7 and provided additional data for validation of the TFA/TFHAL pipe flow models.

Table 2: Test Series Overview

Series No.	Agent	Discharge System	Number of Nozzles	Fires	WSCS Application			Hold Time (time prior to venting) (min)
					Before Agent Discharge	During Agent Discharge	Prior/ During Venting	
1	No	No	No	Yes	---	---	No	---
2	HFP	Standard Navy	4, 8	No	No	No	No	30
3	HFP	Standard Navy	4	Yes	No	No	No	5, 15, 30
4	HFP	Standard Navy	4	Yes	No	Yes	Yes/No	15
5	HFP	Standard Navy	4	Yes	Yes	Yes	Yes/No	15
6	Halon 1301	Standard Navy	4	Yes	Yes/No	Yes/No	Yes/No	15
7	HFP	Modified [a]	4	No	No	No	No	30

a. Larger cylinder valve, flexible hose, and check valve compared to standard U.S. Navy hardware.

The sequence with which critical events occurred during the progression of a test is given in Table 3. Times are referenced to start of agent discharge. The fire pan and spray ignition times are approximate values and are within 10 seconds of the reported value. The Fire 1 pan was manually ignited by the safety team before exiting the space. Fires 1, 2, and 4 sprays were remotely ignited when the safety team had exited.

Compartment supply ventilation (limited protection supply system - LPSS) was 340m^3/min (12000cfm) split 1/3 and 2/3 between the upper and lower levels, respectively. Compartment exhaust ventilation (limited protection exhaust system - LPES) was also in the overhead of the upper level with a ventilation rate of 340m^3/min (12000cfm). The acid stack (elevated stack exhaust - ESE) ventilation system was located in the overhead of the upper level and had an exhaust rate of 140m^3/min (5000cfm). At the start of each test all three ventilation systems are in operation.

During part 1 of Phase II testing, in which tests 3.1 through 3.3 were conducted, longer preburn times were used, (see Table 3). In addition, inadequate preburn supply ventilation occurred due to improper damper settings. The combined effect resulted in self extinguishment of Fire 4 (located in the overhead of the upper level in the hot gas layer) and facilitated extinguishment of Fires 1 and 2. Facilitated fire extinguishment is to be expected from oxygen depletion, similar to what results from larger fires. The preburn time was shortened, and more adequate ventilation was supplied during subsequent tests.

Table 3: Test Sequence

Part 1 Tests 3.1 - 3.3		Part 2 Tests 3.4 - 3.6, 6.1	
Time (min:sec)	Event	Time (min:sec)	Event
- 5:00	Fire 1 pan fire ignited	- 2:30	Fire 1 pan fire ignited
- 3:00	Spray fires (1,2,4) ignited	- 2:15	Spray fires (1,2,4) ignited
-1:30	ERPC started	-1:30	ERPC started
- 1:10	LPSS, LPES and ESE ventilation secured	-1:00	LPSS, LPES and ESE ventilation secured
-1:00	Ventilation dampers closed	- 0:45	Ventilation dampers closed
0:00	Agent discharge	0:00	Agent discharge
15:00 (3.1, 3.2) 30:00 (3.3)	ESE ventilation initiated	5:00 (3.4) 15:00 (3.5, 3.6, 6.1)	ESE ventilation initiated
20:00 (3.1, 3.2) 35:00 (3.3)	LPSS, LPES ventilation initiated	10:00 (3.4) 20:00 (3.5, 3.6, 6.1)	LPSS, LPES ventilation initiated

7.0 FIRE EXTINGUISHMENT AND REIGNITION

Table 4 lists the extinguishment times for the compartment test fires in which WSCS was not activated. Fire out times and reignition were based on observation of IR videos. The fires were extinguished in every test conducted. Attempted reignition was done by impinging an F-76 fuel spray on an ignitor resistively heated to approximately 600°C. Reignition attempts started one minute after agent discharge and were attempted at one minute intervals until a reignition occurred during ESE venting. Reignitions were not attempted at Fire 1 in any test, nor were they attempted during ESE venting in tests 3.1 through 3.3.

Table 4: Fire Extinguishment and Reignition

Test No.	Hold Time (min)	Fire 1		Fire 2		Fire 4	
		Fire Out (sec)	Reignition	Fire Out (sec)	Reignition	Fire Out (sec)	Reignition (min)[a]
3.1	15	7	N.A.[b]	Not Lit	Not Attempted	---[c]	Not Attempted
3.2	15	4	N.A.[b]	<8	No[d]	---[c]	No[d]
3.3	30	8	N.A.[b]	<8	No[d]	---[c]	No[d]
3.4	5	8	N.A.[b]	11	No	5	2
3.5	15	10	N.A.[b]	12	No	11	2
3.6	15	10	N.A.[b]	9	No	4	2
6.1	15	9	N.A.[b]	9	No	6	3

a. From the start of ESE ventilation.
b. Not Applicable.
c. Fire out before agent discharge.
d. No attempts during ESE ventilation.

8.0 HOLD TIME COMPARISON

8.1 Temperature

Figure 3 is a typical temperature profile from a test in which WSCS is not activated. The temperature in the compartment is approximately 25°C (77°F) at the start of the test. At -150 seconds, the time at which the pan fire is ignited (Fire 1), an immediate rise in compartment temperature is observed. Fuel sprays at Fires 1, 2, and 4 are ignited approximately 15 seconds later. The temperature in the space rises until a quasi-steady state temperature is reached. This quasi-steady state temperature is maintained until compartment ventilation (LPSS, LPES, and ESE) is secured. The temperatures range from approximately 75°C (170°F) near the deck of the lower level to approximately 250°C (480°F) near the overhead of the upper level. After ventilation is secured the temperature in the space rises until agent discharge is initiated. The peak temperature at the overhead is approximately 425°C (800°F). When agent discharge is initiated, a precipitous drop in compartment temperature occurs.

Compartment temperature is a critical parameter regarding reentry and compartment reclamation. Table 5 is a comparison of compartment temperatures measured at various heights during the 30 minute hold time test. The temperatures reported were measured at 5, 15, and 30 minutes after agent discharge. The flash point of Naval Distillate F-76 diesel fuel is specified to be 60°C (140°F) or above, (reference (o)). Temperatures above the flash point increase the risk of reflash. Securing the fuel source before exiting the space may not be possible, or unburned fuel may remain on hot decks, engine manifolds, and bulkhead surfaces, and an ignition source may still exist upon reentry.

Table 5: Temperature vs. Hold Time

Height (m)	T (°C) @ 300s	ΔT (°C)	T (°C) @ 900s	ΔT (°C)	T (°C) @ 1800s
4.9	97	11	86	10	76
4.0	90	11	79	8	71
3.0	82	8	74	8	66
2.1	70	6	64	7	57
1.2	64	8	56	4	52
0.3	48	5	43	3	40

Little was gained in terms of temperature reduction when compartment hold time was increased from fifteen minutes to thirty minutes. The temperature measured at the overhead decreased by 10°C (18°F) over that interval. The temperature reduction from five to fifteen minutes is also small compared to the temperature in the compartment at the onset of agent discharge. This does not mean that the compartment reentry time should be reduced from fifteen to five minutes. These temperature data are air temperatures and are specific to these test conditions. Hot surfaces may cause more fuel to evaporate increasing reflash risk. The reduction in temperature after fire suppression is dependent on the fire, intensity, and preburn time. The rate at which heat is dissipated (during the hold time), will decrease with longer preburn times and more intense fires due to higher deck, bulkhead, turbine enclosure, etc., temperatures.

8.2 Hydrogen Fluoride (HF)

Hydrogen fluoride is a toxic by-product that results from a chemical mode of fluorocarbon agent fire suppression. It is an extreme irritant to both the skin and mucous membranes. Concentrations of 50 to 250ppm are considered dangerous, even for brief exposures, (reference (p)). Skin burns produced by HF slowly heal, and subcutateous tissues may be affected. HF is also corrosive and reactive with many materials.

Figure 4 is a typical HF concentration profile. The peak concentration is approximately 5000ppm. There is an exponential concentration decay beginning approximately 30 seconds after the maximum concentration is reached. The HF concentration decreases to approximately 2900ppm five minutes after agent discharge. The HF concentration further decreases to approximately 1400ppm in fifteen minutes. Hydrogen fluoride data is not available for the thirty minute hold time test, but would likely be between 500 and 800ppm based on the decay curve in Figure 4. During the Halon 1301 test, the peak HF concentration was approximately 1100ppm. The HF concentration decreased to approximately 300ppm five minutes after agent discharge, and 100ppm fifteen minutes after agent discharge. The higher HF values measured during HFP fire suppression, compared with Halon 1301, are consistent with previous studies, (references (d), (e) and (q)). These data indicate that a 15 minute reentry time may be too short unless techniques can be used to mitigate HF.

Compartment ventilation, provided it has not been destroyed in the fire incident, could be initiated before compartment reentry to exhaust the high levels of HF. This approach, however, may result in an unwanted reignition if fuel is still present and an ignition source exists. If the fuel source had not been secured before compartment evacuation or remotely secured, and if an ignition source still exists, the compartment's total flooding fire protection will be lost as agent is exhausted and air admitted. Data in Table 4 show that reignitions can occur within three minutes of ventilation system activation for this particular ventilation rate. Alternate techniques to mitigate post-fire suppression HF, or reduce initial HF generation should be explored. The innovative WSCS technique shows promise in accomplishing both tasks, (reference (j)).

8.3 Gas Concentrations

Figure 5 shows the concentration profiles of O_2, CO_2, and HFP measured during a fifteen minute hold test. The gases were continuously sampled from the upper level of the compartment. Carbon monoxide is not shown, but reaches approximately 0.35% (v/v) just before agent discharge, and decreases to approximately 0.28% (v/v) after discharge. The data between 180 seconds and 800 seconds are not shown since there is little change in the measured concentrations over that interval. The slight change that is observed is a result of both compartment gas mixing and air infiltration. This is apparent by the rise in oxygen concentration with a concomitant decrease in CO_2, HFP, and, although not shown, CO.

Approximately 150 seconds before agent discharge, and soon after Fire 1 ignition, there is a simultaneous O_2 concentration decrease and CO_2 increase. The rate of change in concentration of both species decreases until approximately 60 seconds before agent discharge when the ventilation is secured. The concentrations of O_2 and CO_2 then change at a greater rate than before ventilation closure until agent discharge. At the initiation of agent discharge the CO_2 concentration rapidly decreases to approximately 4.7%, while O_2 levels off at approximately 11.1%. In contrast, the concentrations of O_2 in the lower level at agent discharge are 15.7% and 15.9% as measured by a continuous O_2 analyzer and gas chromatographic grab sample, respectively. The difference in species concentrations is due to convection and buoyancy effects.

Smoke, CO_2, and CO rise to the upper layer of the compartment and displace O_2. This explains the disparity in species concentrations between the upper and lower levels of the compartment.

The concentration of HFP rises to an equilibrium concentration of approximately 12% after agent discharge. The higher measured HFP concentration, i.e., the difference in measured concentration and the design concentration is a result of the lower air density (higher temperature) in the compartment. It may be expected that 12% HFP would result in a 12% relative decrease in CO_2 concentration. This is not evident in Figure 5. The hot, buoyant, less dense, upper combustion gas layer is being mixed with the cooler, more dense, lower level gases due to the energetic agent discharge. The CO_2 concentration in the lower level is 4% at agent discharge and *rises* to approximately 4.5% thirty seconds after agent discharge.

The exponential changes in measured concentrations that occur at approximately 930 seconds signifies the initiation of ESE ventilation. A second exponential change occurs at 1200 seconds with the initiation of LPSS and LPES ventilation.

The concentrations of O_2, CO_2, and CO measured are specific to this test compartment, and under these test conditions. The concentrations of these species will vary depending on fire preburn time, fire intensity, fuel, ventilation, and compartment or room construction design and materials. This variability can lead to the formation of greater or lesser quantities of these species, and the formation of other potentially more toxic species. The rapidity with which a compartment can be reentered, regarding gaseous concentrations, is largely dependent on the personnel protection of the reentry team.

9.0 SUMMARY

Several Series of tests were conducted for post-fire suppression compartment characterization. In all of the tests conducted, the compartment test fires were extinguished. Reignitions did not occur between fire suppression and subsequent ventilation initiation in any of the tests. Reignitions did occur between two and three minutes after ESE ventilation initiation. During tests in which the WSCS was not used, HFP generated four to five times as much HF as did Halon 1301. This is consistent with previous studies, (references (d), (e), and (f)).

Fleet Doctrine compartment reentry time is currently fifteen minutes after Halon 1301 fire suppression. The optimum hold time before ventilation initiation is specific to each fire incident. Initiation of ventilation before reentry can lead to unwanted reignition and loss of total flooding fire protection. This report addresses temperature reduction and HF concentration resulting from HFP fire suppression. It is to aid in the determination of acceptable hold times for HFP shipboard applications. Techniques to expedite ventilation, a primary goal after reentry, can be developed to accelerate compartment reclamation. Use of WSCS may render the fifteen minute reentry time sufficient for HFP fire suppression, and expedite ventilation initiation, (reference (j)).

10. REFERENCES

(a) H.W. Carhart, F.W. Williams, and T.A. Toomey, "The Ex-Shadwell - Full Scale Fire Research and Test Ship," NRL Memo Report 6074, October 6, 1987.

(b) R.S. Sheinson, A. Maranghides, and J. Krinsky, "Test Plan for Halon Replacement Agent Testing on the *ex*-USS SHADWELL," NRL Letter Report 6180/0470.1, September 19, 1995.

(c) R.S. Sheinson, A. Maranghides, D. Barylski, B.H. Black, T. Friderichs, M. Peatross, W.D. Smith; "Total Flooding Agent Distribution Considerations," Proceedings of the Halon Options Technical Working Conference, May 9-11, 1995, Albuquerque, NM, pp. 109-124.

(d) R.S. Sheinson, A. Maranghides, H.G. Eaton, D. Barylski, B.H. Black, R. Brown, H. Burchell, P. Byrne, T. Friderichs, C. Mitchell, M. Peatross, G. Salmon, W.D. Smith, and F.W. Williams, "Large Scale (840 m^3) HFC Total Flooding Fire Extinguishment Results," Proceedings of the Halon Options Technical Working Conference, May 9-11, 1995, Albuquerque, NM, pp. 637-648.

(e) R.S. Sheinson, A. Maranghides, T. Friderichs, B.H. Black, W. Smith, and M. Peatross, "Recommendations for the LPD-17 Main and Auxiliary Machinery Rooms Total Flooding Fire Suppression Systems," NRL Letter Report 6180/0193.1, July 24, 1995.

(f) B.H. Black, R.S. Sheinson, A. Maranghides, T.J. Friderichs, M. Peatross, and W.D. Smith, "Real Scale Halon Replacement Testing Aboard the *ex*-USS SHADWELL," Proceedings of the International Conference on Fire Research and Engineering, September 10-15, 1995, Orlando, FL, pp. 82-87.

(g) A. Maranghides, R.S. Sheinson, B.H. Black, T.J. Friderichs, M. Peatross, and W.D. Smith, "Agent Concentration Inhomogeneities and Dilution in Real Scale Halon Replacement Testing," Proceedings of the International Conference on Fire Research and Engineering, September 10-15, 1995, Orlando, FL, pp. 119-126.

(h) R.S. Sheinson, A. Maranghides, and J. Krinsky, "Test Plan for Halon Replacement Post Fire Suppression Compartment Characterization Testing on the *ex*-USS SHADWELL," NRL Letter Report 6180/0592, 01 September 1995

(i) R.S. Sheinson, A. Maranghides, and J. Krinsky, "Modification of the Test Plan *Ex*-USS SHADWELL," NRL Letter Report 6185/00070, 27 February 1996.

(j) A. Maranghides, R. S. Sheinson, B.H. Black, M. Peatross, and W.D. Smith, "The Effects of a Water Spray Cooling System During Real Scale Halon 1301 Replacement Testing on Post Fire Suppression Compartment Reclamation," NRL Letter Report 6185/0014A, 7 January 1997

(k) A. Maranghides, R. S. Sheinson, T. Friderichs, B.H. Black, and M. Peatross, "Discharge System Modifications Effects on Agent Concentration Distribution: Real Scale Halon Replacement Testing," Proceedings of the Halon Options Technical Working Conference, May 7-9, 1996, Albuquerque, NM, pp. 515-526.

(l) Naval Ships' Technical Manual, S9086-S3-STM-010, Chapter 555, Section 6, "Machinery Space Firefighting Doctrine for Class B Fires in Surface Ships," Naval Sea Systems Command, 03G2, June 1, 1993.

(m) S.H. Hoke and C. Herud, "Performance Evaluation of a Halogen Acid Gas Analyzer," Proceedings of the Halon Options Technical Working Conference, May 7-9, 1996, Albuquerque, NM, pp. 577-584.

(n) Bird, E.S., Giesecke, H.D., Hillaert, J.A., Friderichs, T.J., and Sheinson, R.S., "Development of a Computer Model to Predict the Transient Discharge Characteristics of Halon Alternatives," Proceedings of the Halon Options Technical Working Conference, May 3-5, 1994, Albuquerque, NM, pp. 95-103.

(o) Military Specification, Fuel, Naval Distillate, MIL-F-16884J, Naval Sea Systems Command, SEA 03R42, Washington, DC, 31 May 1995.

(p) Sax, N.I., "Dangerous Properties of Industrial Materials," Rienhold Publishing Co., Second Edition, 1963, p. 884.

(q) R.S. Sheinson, H.G. Eaton, B.H. Black, R. Brown, H. Burchell, A. Maranghides, C. Mitchell, G. Salmon, W.D. Smith; "Halon 1301 Replacement Total Flooding Fire Testing, Intermediate Scale," Proceedings of the Halon Options Technical Working Conference, May 3-5, 1994, Albuquerque, NM, pp. 43-53.

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Photograph 1

Photograph 2

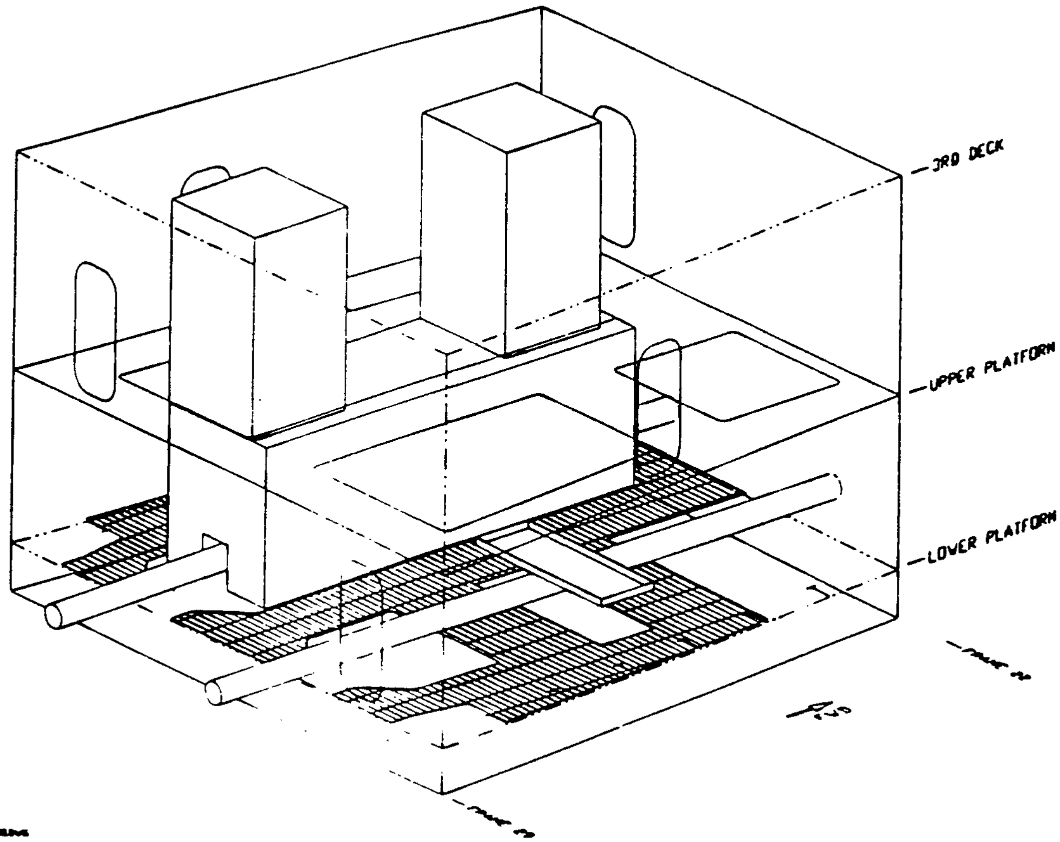


Figure 1

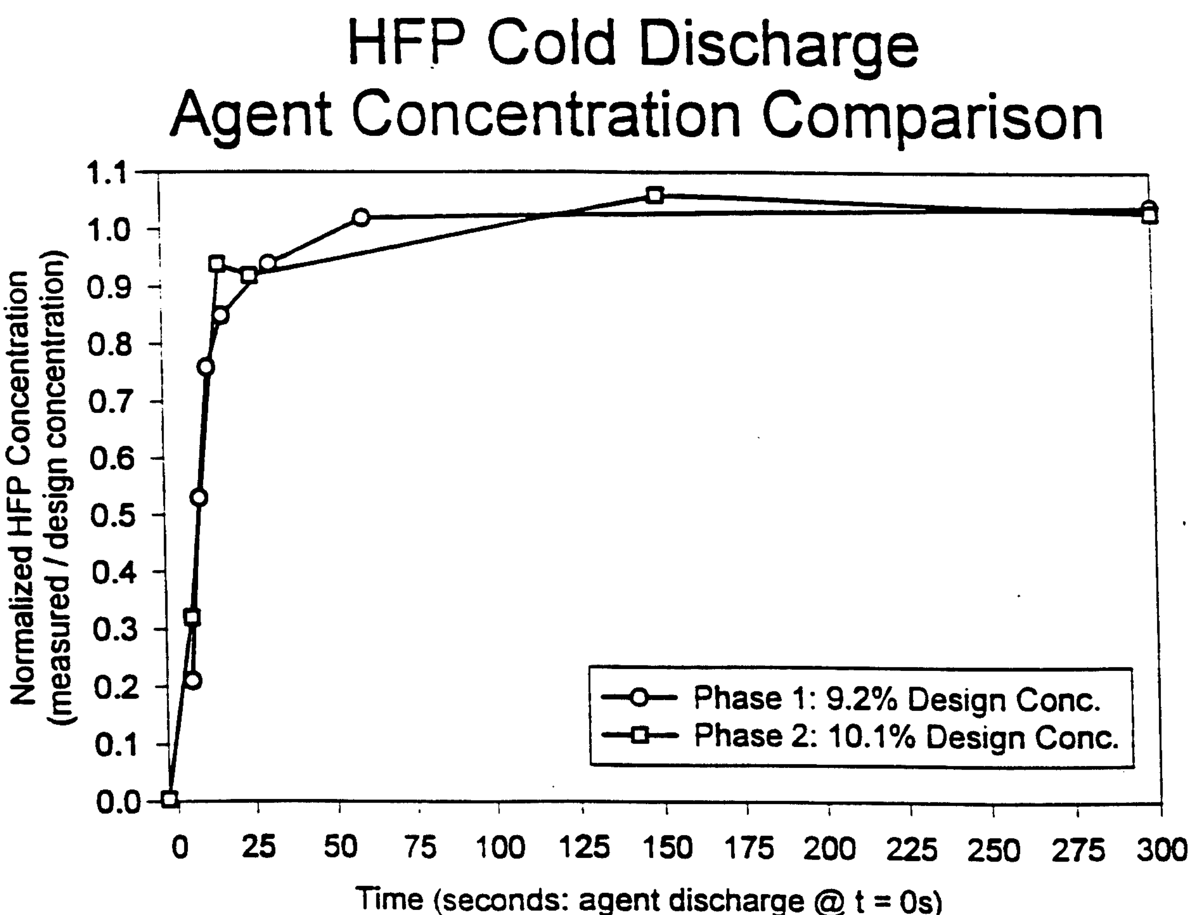
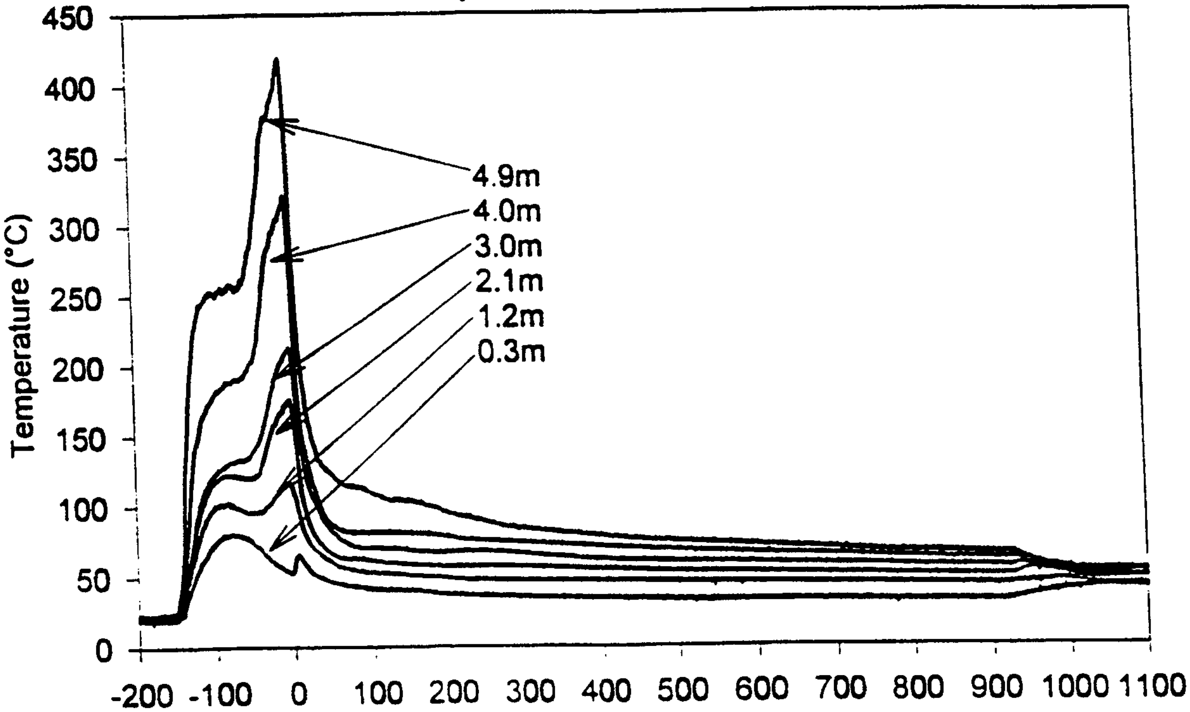


Figure 2

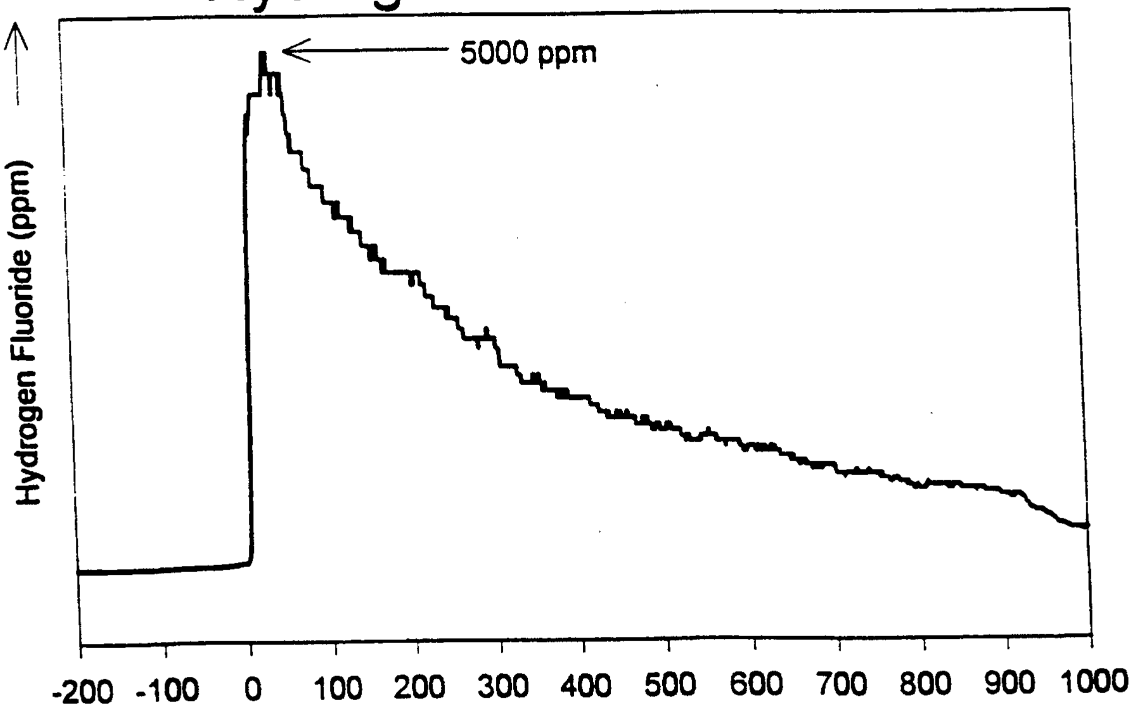
HFP Fire Suppression
Temperature Profiles



Time (seconds: agent discharge @ t = 0s)
(WSCS not Activated)
Figure 3

Thermocouple Tree: 6-27-1
ex-USS SHADWELL
Phase 2, Test 3.6

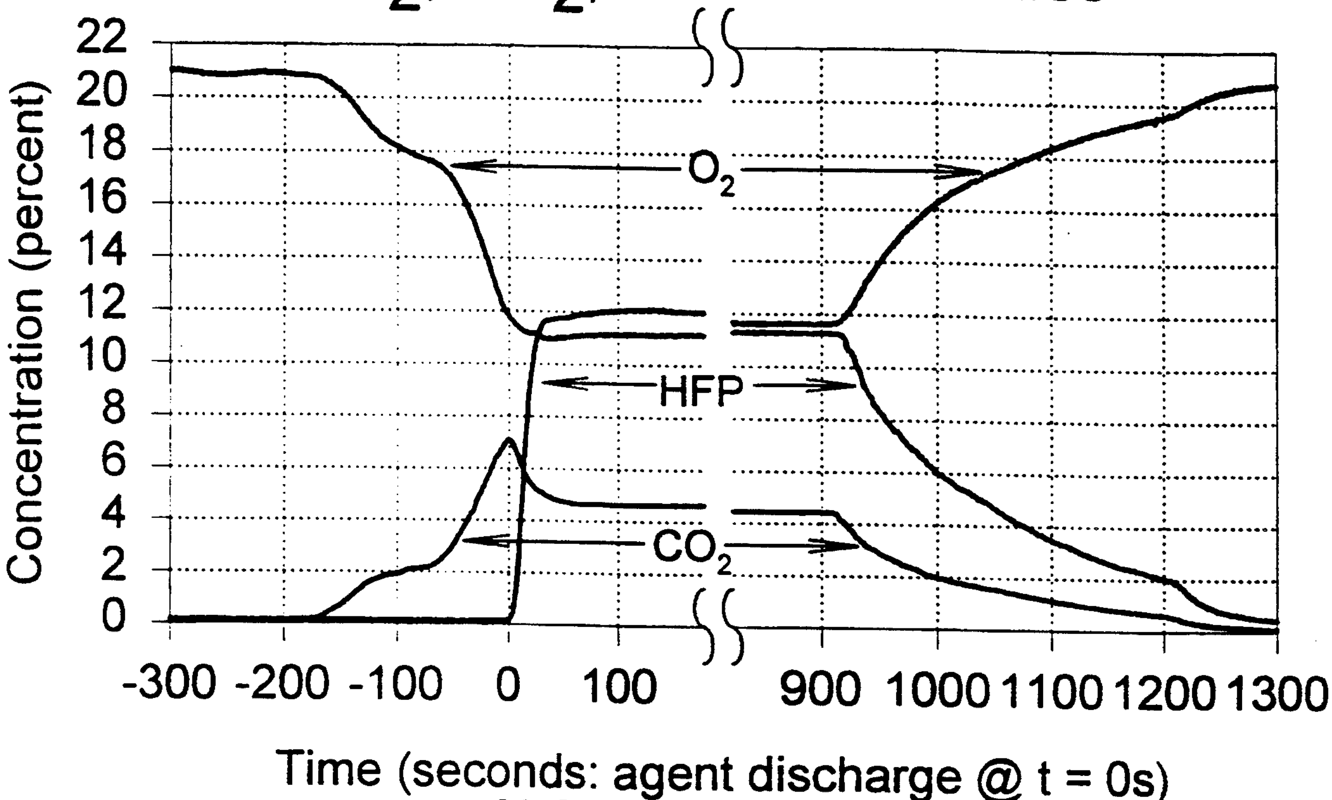
HFP Fire Suppression
Hydrogen Fluoride Profile



Time (seconds: agent discharge @ t = 0s)
(WSCS not Activated)
Figure 4

HF Analyzer: 4-22-3
ex-USS SHADWELL
Phase 2, Test 3.6

HFP Fire Suppression
O_2, CO_2, and HFP Profiles



(WSCS not Activated)

Figure 5

Analyzer Loop: 4-22-0
ex-USS SHADWELL
Phase 2, Test 3.6